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AA398 AA40Y AA400 AA402 AA404 AA406 AA409
AA439 AA459 AA48Y AA499 AA50X AA501 AA503
AA505 AA507 AA509 AA529 AA549 AA55Y AA553
AA555 AA562 AA565 AA568 AA57Y AA571 AA574
AA577 AA579 AA599 AA609 AA629 AA67X AA671
AA673 AA675 AA677 AA679 AA68X AA681 AA683
AA685 AA687 AA689 AA69X AA693 AA695 AA697
AA699 AA70X A740 A741 A742 A78Y A782 A783
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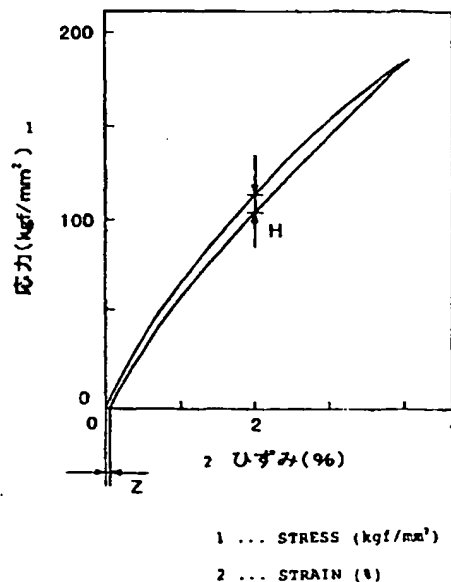
JP 020011723 A US 5069226 A1

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(54) Abstract Title

NiTi-type medical guide wire and method of producing the same

(57) A medical guide wire made of NiTi type alloy, the wire having a high-elasticity property over a wide strain range, superior linearity, and suitable stress-strain curve shapes and properties in tensile tests. The wire is obtained by subjecting a cold-worked NiTi type alloy wire to mechanical corrective processing under predetermined twisting shearing strain and temperature conditions while applying a predetermined tension thereto, and since the wire exerts superior pushability, torque transmittability and repetitive insertability for medical guide wires, it is suitable for use as a catheter guide wire, an endoscope guide wire or the like.



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INT CL⁷ A61M 25/09 , B21F 7/00 , C22F 1/10
Jitsuyo Shinan Kolo 1926-1996 Toroku Jitsuyo Shinan
Koho 1994-2000
KokaiJitsuyo Shinan Koho 1971-2000 Jitsuyo Shianan
Toroku Koho1996-2000

FIG.1(A)

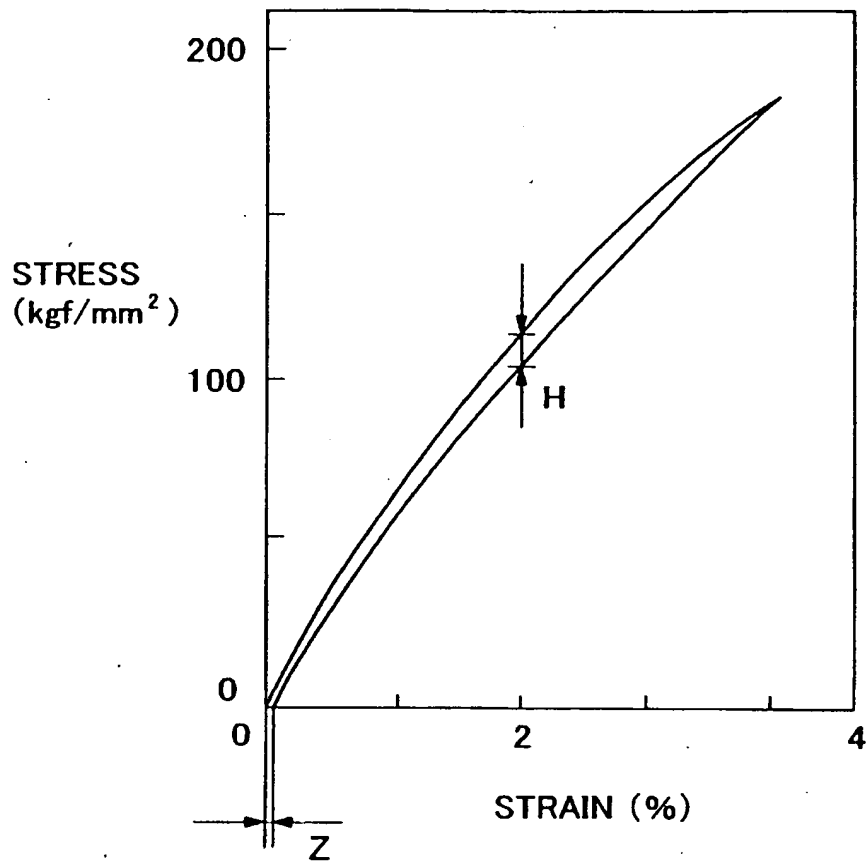


FIG.1(B)

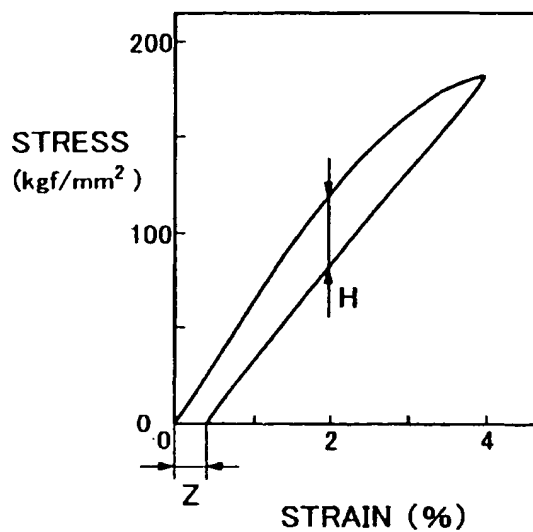


FIG.1(C)

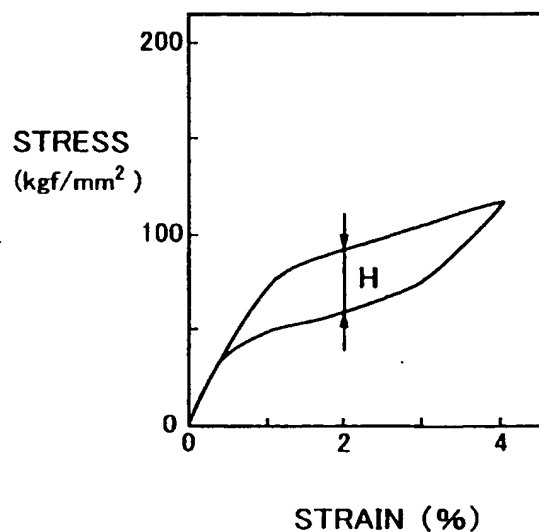


FIG.1(D)

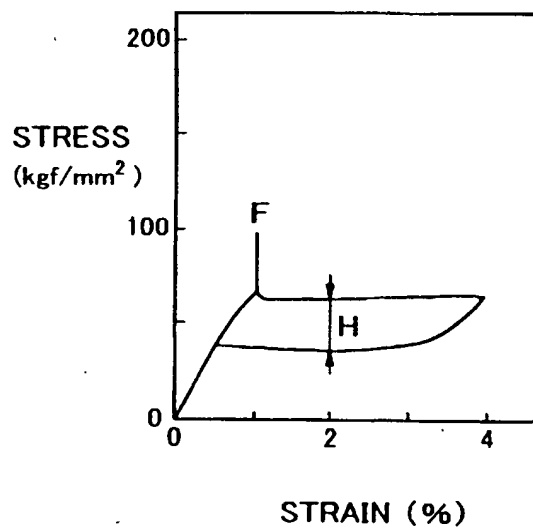


FIG.1(E)

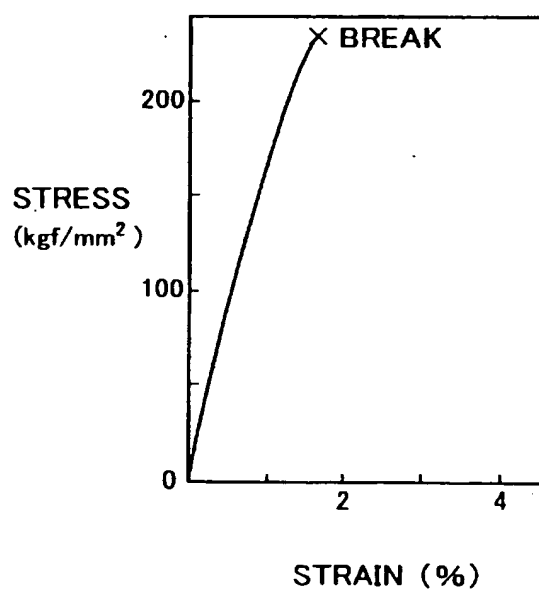
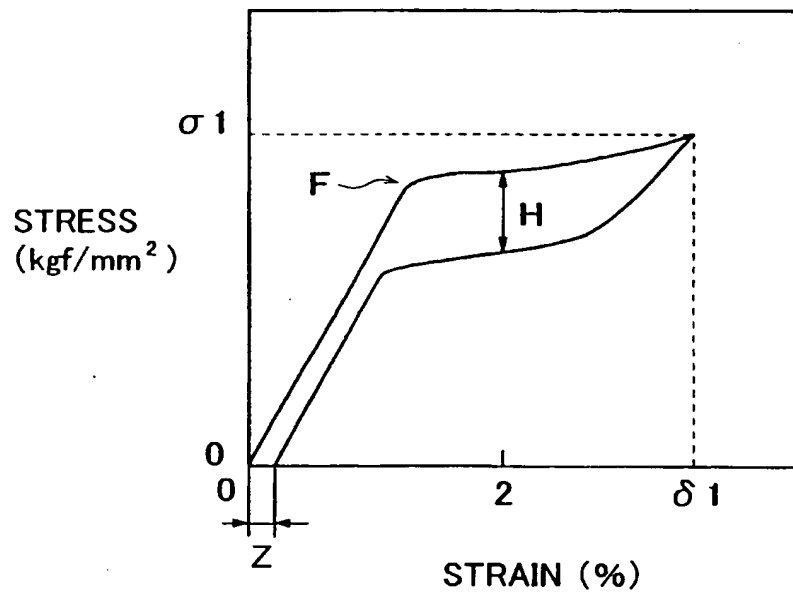


FIG.2



APPEARENT MODULUS OF
ELASTICITY $E_d = \sigma_1 / \delta_1$

FIG.3

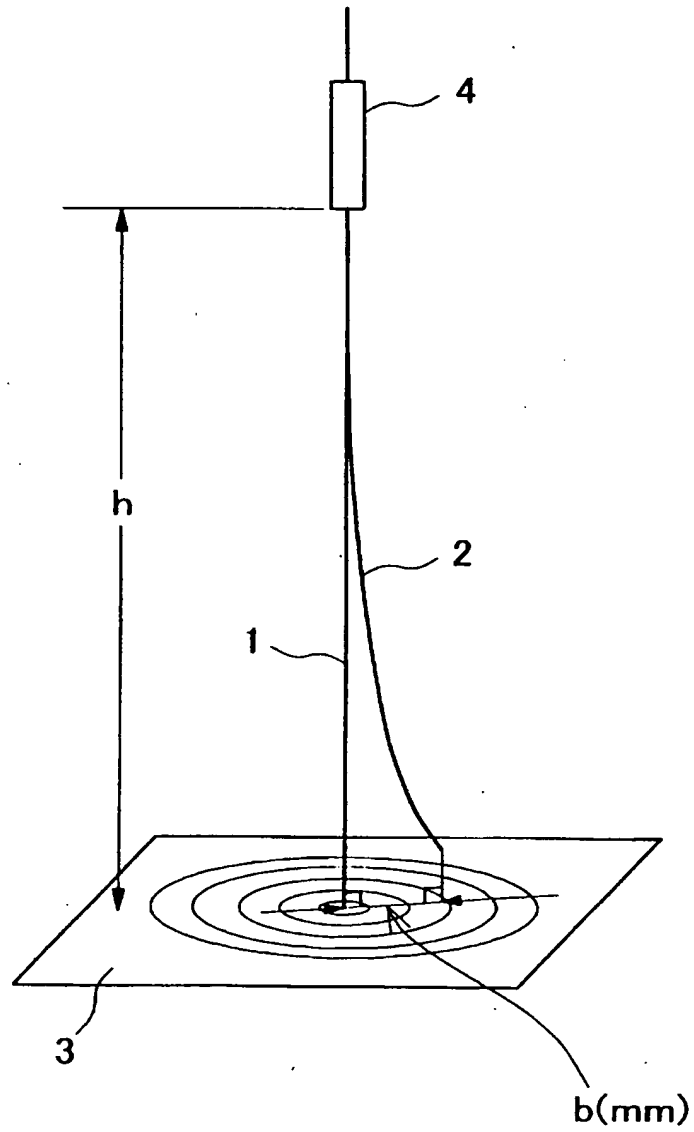


FIG.4

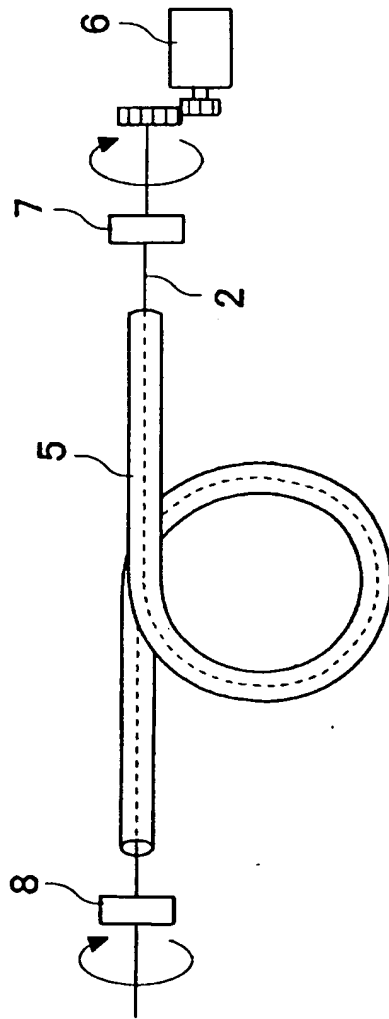


FIG.5

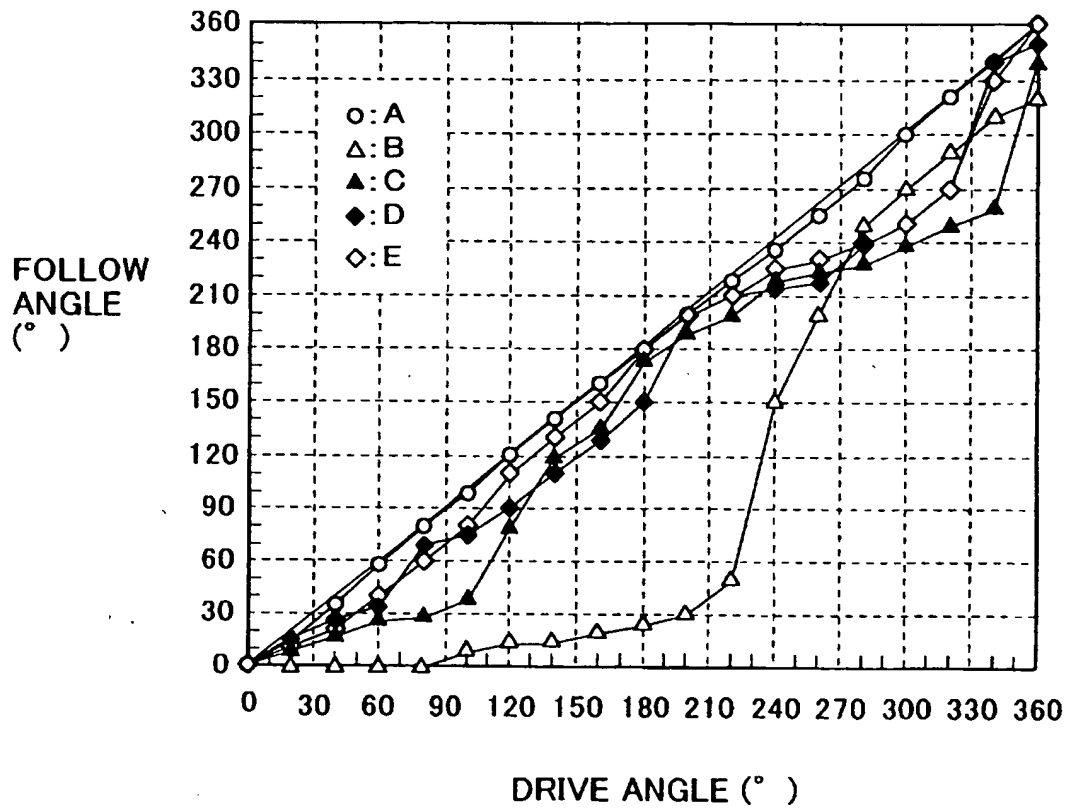


FIG.6(A)

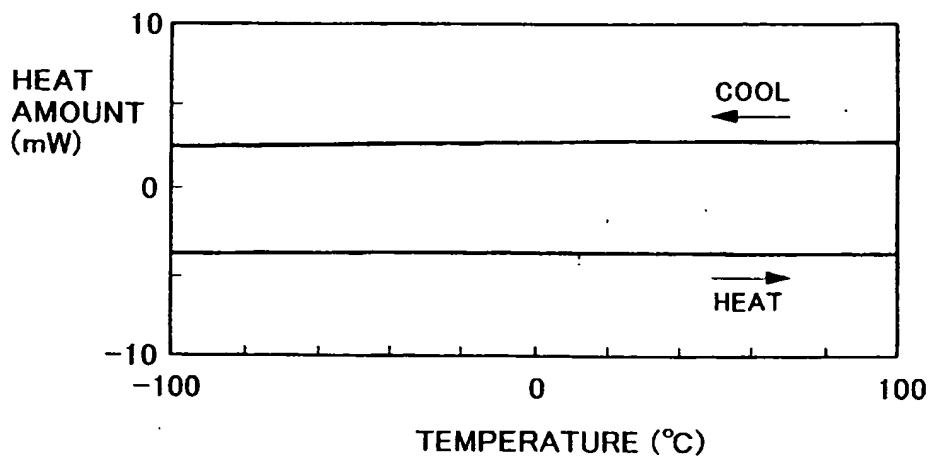


FIG.6(C)

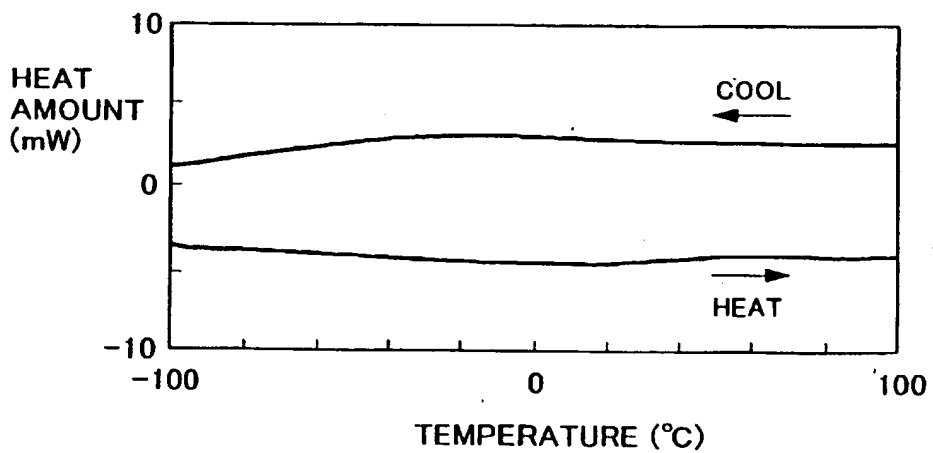


FIG.6(D)

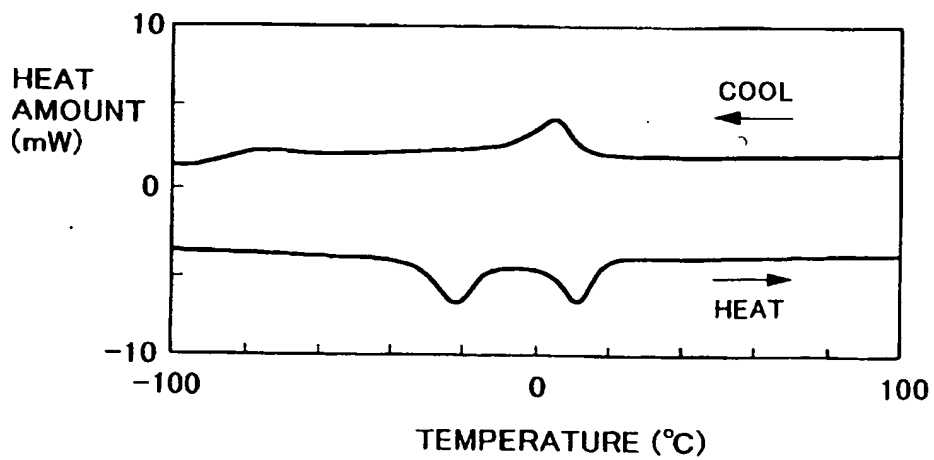


FIG.7

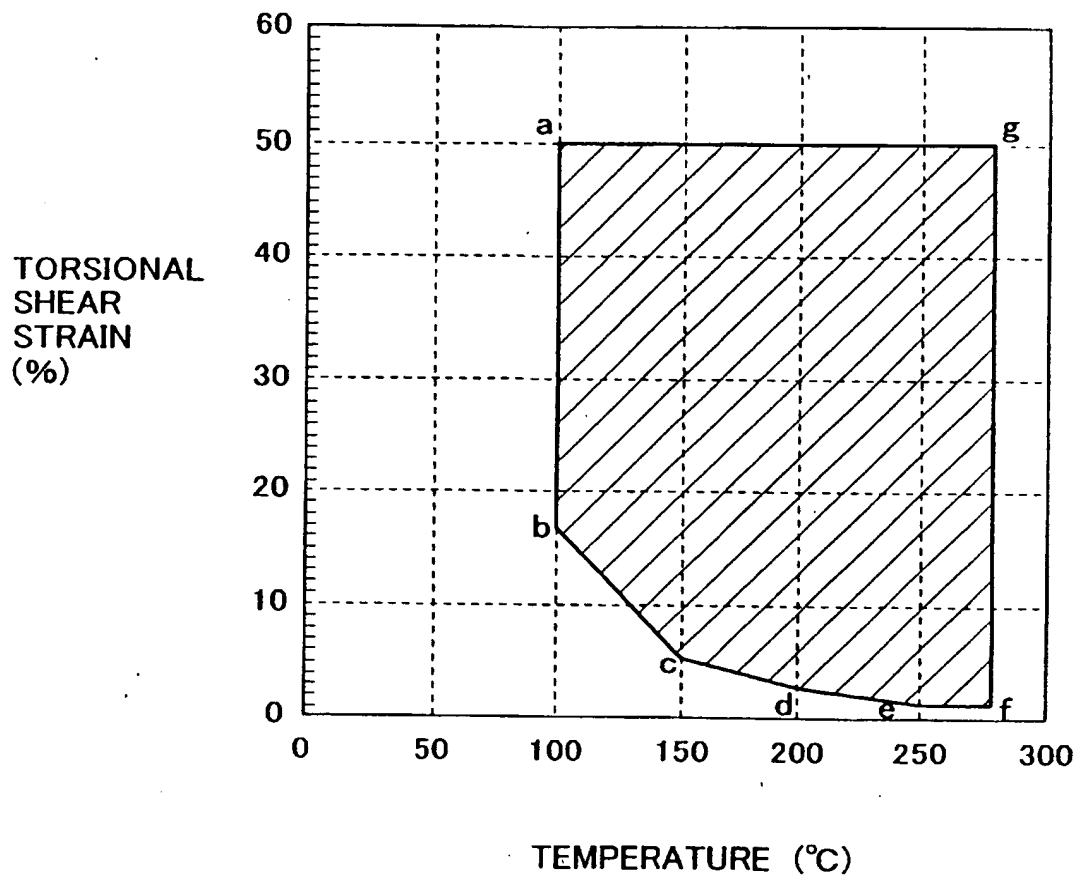


FIG.8

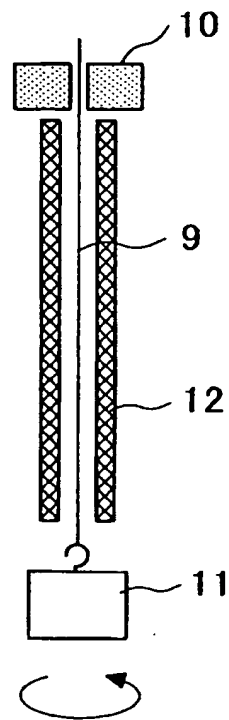


FIG.9

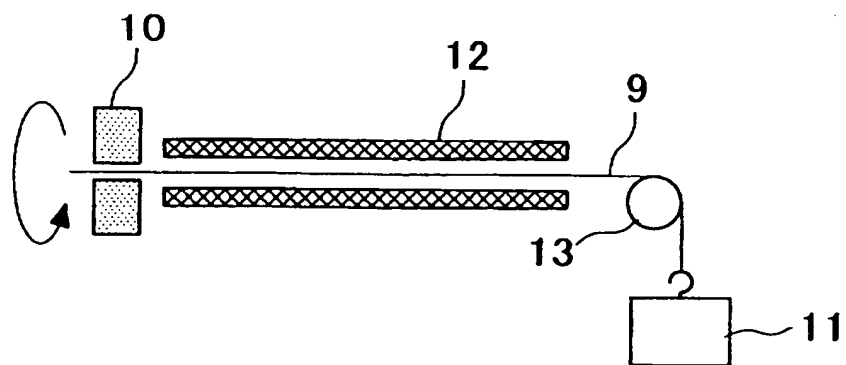
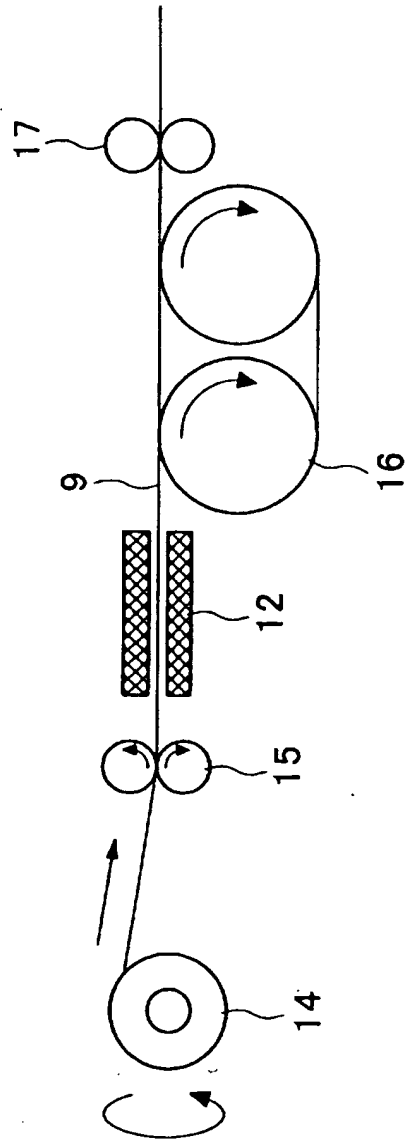


FIG.10



LIST OF REFERENCE NUMERALS

- 1 COMPLETELY STRAIGHT WIRE
- 2 TEST WIRE OF TOTAL LENGTH OF 1.5 M
- 3 FLOOR SURFACE
- H DISTANCE (1.5 M) IN CASE OF COMPLETELY STRAIGHT WIRE
- B DISTANCE INDICATING STRAIGHTNESS OF WIRE
- 4 WIRE HOLDER (MADE OF SUS)
- 5 POLYETHYLENE TUBE
- 6 MOTOR
- 7 ROTARY ENCODER ON DRIVE SIDE
- 8 ROTARY ENCODER ON FOLLOWING SIDE
- 9 PRODUCED WIRE
- 10 HOLDER
- 11 WEIGHT
- 12 HEATING FURNACE
- 13 PULLEY
- 14 BOBBIN
- 15 PINCH ROLLER
- 16 CAPSTAN
- 17 PINCH ROLLER

DESCRIPTION

NiTi-BASED MEDICAL GUIDEWIRE AND

5 METHOD OF PRODUCING THE SAME

TECHNICAL FIELD

The present invention relates to a medical guidewire comprised of an NiTi-based alloy having a high elasticity
10 over a wide range of strain and a method of producing the same, more particularly relates to a catheter guidewire etc. made of an NiTi-based alloy wire having a straightness, and shape and characteristics of a stress-strain curve preferable for a medical guidewire.

15 BACKGROUND ART

Medical guidewires include catheter guidewires and endoscope guidewires. Here, the explanation will be given taking as an example a catheter guidewire.

A catheter guidewire is used for guiding a catheter
20 (thin tube) for treatment or examination into a blood vessel and leaving it in the affected area.

Therefore, a catheter guidewire is required to have enough flexibility and shape recovery for insertion into branched and meandering blood vessels without damaging
25 them by conforming to the shape of the blood vessels. The

demand for this characteristic has become much stronger in recent years as catheters are now being introduced close to the end of blood vessels.

In the past, stainless steel wire has been used for the catheter guidewire, however it suffers from the disadvantage that stainless steel wire permanently deforms when passed through a sharply curved blood vessel. The wire ends up remaining curved and can no longer proceed further or cannot be reinserted.

Therefore, three types of wire have been recently proposed: (1) a superelastic wire using the superelasticity of an NiTi-based alloy (Japanese Examined Patent Publication (Kokoku) No. 2-24550, Japanese Examined Patent Publication (Kokoku) No. 2-24548, and Japanese Examined Patent Publication (Kokoku) No. 2-24549), (2) a wire obtained by cold drawing an NiTi-based alloy and then heat treating it at a low temperature (hereinafter referred to as "cold drawn, low temperature heat-treated wire") (Japanese Examined Patent Publication (Kokoku) No. 6-83726 and U.S. Patent No. 5230348), and (3) a cold drawn wire obtained by only cold drawing (WO97/18478).

The above superelastic wire of type (1) utilizes the characteristic that deformation caused by stress-induced martensitic transformation is recovered by reverse

transformation when unloaded, so it is much more flexible compared with conventional stainless steel wire and has a strong shape recovery, i.e., so-called superelasticity.

Note that superelasticity is given by heat treatment (shape memory heat treatment, for example, 400 to 500°C) for giving superelasticity after cold drawing.

Superelastic wire, however, has a yield point F on the stress-strain curve as shown in Fig. 1D. Stress is not increased even if more strain is given when exceeding the point, so there are the disadvantages that the wire is poor in pushability, cannot be inserted close to an end of the blood vessel, does not allow rotation by the holder to be easily conveyed to the tip of the wire, and therefore is poor in operability (torque transmission).

Also, cold drawn, low temperature heat-treated wire of type (2) is produced by shaping an NiTi-based alloy wire having a cold working rate of 35 to 50% to make it straight (for example, holding it at 350 to 450°C for 10 to 30 minutes). As shown in the stress-strain curve of Fig. 1C, almost no stress-induced martensitic transformation or reverse transformation occurs and the apparent modulus of elasticity is large, so the pushability is excellent.

However, there is a large stress difference H, between loading and unloading, at a strain of 2% after

applying strain up to 4%, then unloading. Simultaneously, sufficient straightness cannot be obtained by shaping. Therefore, the torque transmission declines.

The cold drawn wire of type (3) has the advantage, as shown in Fig. 1B, that the apparent modulus of elasticity is larger than that of the (2) cold drawn, low temperature heat-treated wire, however, since there is a large residual strain after deformation, the wire ends up permanently deforming when passed through a curved blood vessel.

Further, just cold working is not enough to obtain a wire having a high straightness, so the torque transmission is poor. Also, in spite of the high modulus of elasticity, since the straightness is low, the pushability is inferior for the high modulus of elasticity. Further, there is a large residual strain and therefore a problem in reusability. Especially, in wires of the types (2) and (3), the low straightness is a problem. Improvement of this point has been desired.

As explained above, the conventional superelastic type wire, low temperature heat treated type wire after cold drawing cold drawn type wire do not show the sufficient characteristics for use as a medical guidewire. Development of a wire superior in all of the pushability, torque transmission, and reusability

required for use as a medical guidewire has therefore been desired.

DISCLOSURE OF INVENTION

In view of this background art, the present
5 inventors closely analyzed the relationship between characteristics in use required for a medical guidewire and mechanical characteristics of the guidewire and discovered that the required characteristics of the above guidewire can be secured by giving the guidewire specific
10 mechanical characteristics and therefore attempted to give a guidewire a specific shape and characteristics of a stress-strain curve as determined by tensile tests.

Namely, the present inventors read a variety of characteristics from the stress-strain curve as
15 determined by the above tensile tests and found the relationship between the characteristics of the wire and the characteristics in use required for medical guidewire.

Then, they found that the straightness of the wire
20 and the following four characteristics, that is, a total of five characteristics, are closely related with a medical guidewire.

Among the five characteristics, the (1) straightness has to be good from both the viewpoints of reusability
25 (insertability) and torque transmission when used as a

medical guidewire.

The other four characteristics are the shape and characteristics of the stress-strain curve as found by tensile tests of the wire, that is, (2) the shape, (3) 5 the apparent modulus of elasticity, (4) the stress difference (that is one of the parameters with reference to stress hysteresis) at a constant strain (strain of 2%) between loading and unloading of a load, and (5) strain recovery after removing strain (residual strain).

10 Here, the maximum strain at the tensile tests was made 4%. The stress-strain curve was obtained by giving 4% strain, then reducing the load to 0.

The reason why the maximum strain was made 4% in this way was that by conducting a tensile strength test 15 up to a strain of 4%, it is possible to obtain sufficient information enabling evaluation of the material characteristics under the standard conditions of use of medical guidewire.

The inventors conducted further studies and as a 20 result learned that the relationship between the characteristics (1) to (5) of wire and characteristics in use of medical guidewire becomes as follows:

Namely, the pushability is affected by the above (2) and (3). The (2) shape of the stress-strain curve should 25 be one of a monotonous increase in stress v.s. strain

without any yield points or inflection points. A guidewire like the conventional superelastic wire which has a yield point and where the gradient of the stress with respect to the strain decreases when the yield point is exceeded easily buckles in a blood vessel and is difficult to push further in. A guidewire which has a high (3) apparent modulus of elasticity has stiffness as a wire and can be easily inserted further.

Further, the torque transmission is affected by the characteristics (1) and (4). A guidewire which has a low (1) straightness has a larger frictional force with the inner wall of the blood vessel. The torque is no longer transmitted accurately and the guidewire cannot be inserted close to the end of the blood vessel with good operability. Also, a guidewire which has a large (4) stress difference is slow to turn at its tip portion in response to rotation of the wire by the physician at its holder.

Also, when looking at repeated insertability (reusability), the smaller the (5) residual strain, the more the insertion can be repeated to the same patient. It is necessary to significantly reduce the residual strain for enabling repeated insertion.

The present inventors engaged in in-depth studies based on the above discoveries and thereby completed the

present invention.

Accordingly, an object of the present invention is to solve the above problems and to provide an NiTi-based alloy wire having high elasticity characteristics over a wide range of strain and the above characteristics (1) to (5) and thereby provide an NiTi-based medical guidewire displaying excellent pushability, torque transmission, and repeated insertability when used as a medical guidewire.

10 Another object of the present invention is to provide a method of producing a medical guidewire displaying the above characteristics.

The present invention will be explained in detail below.

15 A first aspect of the present invention relates to a medical guidewire.

Namely, the present invention provides a medical guidewire comprised of an NiTi-based alloy wire made of a wire produced by mechanically straightening a cold drawn NiTi-based alloy wire and (1) having a straightness of 20 mm/1.5 m as determined by the suspension method, and having a shape and characteristics of the stress-strain curve by a tensile test which satisfy the following requirements (2) to (5), and thereby displaying excellent pushability, torque transmission, and reusability as a

25

medical guidewire.

Requirement (2) to (5):

(2) A monotonous increase in stress up to strain of 4% without any yield points or inflection points and no stress-induced martensitic transformation shown at all.

(3) High elasticity characteristics over a wide range of strain and an apparent modulus of elasticity of 3000 kgf/mm² or more at a strain of 4%.

(4) A residual strain after loading up to strain of 4% then unloading, is not more than 0.15%.

(5) A stress difference, between loading and unloading, at a strain of 2% during unloading after loading up to 4%, is not more than 15 kgf/mm².

The present invention will be explained in further detail below.

First, Fig. 2 is a view of a general stress-strain curve in a tensile test of an NiTi-based alloy. The yield point F, apparent modulus of elasticity $E_d = \sigma_1 / \delta_1$, stress difference H, and residual strain Z used in the explanation of the present invention are defined as shown in the figure.

The guidewire of the present invention is produced by mechanical straightening a cold drawn NiTi-based alloy wire and then using the special process of production explained in detail later to obtain a wire having an

excellent (1) straightness.

The straightness of the NiTi-based alloy wire of the present invention as determined by the suspension method is not more than 20 mm/1.5 m.

5 Here, the straightness is a value measured by the suspension method, that is, as shown in Fig. 3, a value indicated by a distance b (mm) in the horizontal direction on a floor surface 3 between a tip position of a wire 2 tested when feeding out the wire 1.5 m from a wire fixing tube 4 and a tip position of a completely
10 straight wire 1. Accordingly, the distance from the lower surface of the fixing tube 4 to the floor surface during the test varies in accordance with the bent condition of the wire.

15 The straightness of the wire has a large effect on the torque transmission of the characteristic of use of a medical guidewire. Namely, a wire having a high (excellent) straightness excels in torque transmission.

 The inventors conducted experiments on the
20 relationship between the wire straightness and the torque transmission using an apparatus shown in Fig. 4.

 Namely, they found the torque transmission by twisting one end of a wire 2 passed through a loop-shaped polyethylene tube 5 by a drive (motor 6) for a
25 predetermined angle (drive angle) and measuring the

follow angle of the other end of the wire at that time by rotary encoders 7 and 8.

The tested samples are the samples shown in Table 3 of a first embodiment explained later, that is, Sample
5 No. 1 (A. Wire of present invention, straightness of 19 mm), Sample No. 23 (B. Cold drawn wire, straightness of 105 mm), Sample No. 24 (C. Cold drawn, low temperature heat-treated wire, straightness of 70 mm), Sample No. 25 (D. Superelastic wire, straightness of 30 mm), and Sample
10 No. 26 (E. Highly worked stainless steel wire, straightness of 30 mm).

The results of measurement of the torque transmission are shown in Fig. 5.

The wire A of the present invention having a high
15 straightness has a drive angle and follow angle in a substantially 1:1 correspondence, and exhibits an excellent torque transmission. As opposed to this, the wires of the related art having a low straightness exhibited in delay in following drive. In particular,
20 the cold drawn wire exhibited a large delay. This was due to the low straightness.

Next, the guidewire of the present invention had a shape and characteristics of the stress-strain curve in a wire tensile test, as shown in Fig. 1A, where the stress
25 increases monotonously up to a strain of 4% with no yield

points F or inflection points and no stress-induced martensitic transformation is exhibited at all.

Here, the fact that an NiTi-based alloy wire according to the present invention does not show any stress-induced martensitic transformation at all will be explained.

Differential scan calorimetry (DSC) was carried out for investigating the phase changes of an alloy wire for Sample No. 1 (A. Wire of present invention) shown in Table 3 of the first embodiment which will be explained later on and for Sample No. 24 (C. Cold drawn, low temperature heat-treated wire of the related art) and Sample No. 25 (D. Superelastic wire of the related art) for comparison. The results are shown in Figs. 6A, 6C, and 6D.

The NiTi alloy wire of the present invention shown in Fig. 6A does not exhibit a peak indicating that a martensite phase transforms to a parent phase. Superelasticity and martensitic transformation have a close relationship with each other. A wire which does not undergo martensitic transformation does not exhibit superelasticity.

As opposed to this, the cold drawn, low temperature heat-treated NiTi alloy wire of the related art shown in (C) exhibited a slight but broad peak.

Also, the superelastic NiTi alloy wire of the related art shown in (D) clearly exhibited a peak indicating that the martensite phase transformed to the parent phase.

5 Furthermore, the inventors investigated the above three samples for phase transformation by X-ray analysis at -40°C, room temperature, and 60°. As a result, the NiTi alloy wire of the present invention failed to exhibit any changes corresponding to transformation
10 between a parent phase and martensite phase in accordance with temperature at an X-ray peak.

On the other hand, the cold drawn, low temperature heat-treated and superelastic NiTi alloy wires of the related art were observed that of the X-ray peak is
15 changed and the phase transformation appears due to a change of the temperature.

In this way, it was confirmed that the NiTi-based alloy wire according to the present invention did not exhibit any stress-induced martensitic transformation at
20 all.

Next, the guidewire of the present invention exhibits the characteristics, as follows: (3) high elastic characteristics over a wide range of strain and a large apparent modulus of elasticity $E_d [\sigma/\delta(0.04)]$ of
25 3000 kgf/mm² or more at a strain of 4%, (4) a small

stress difference H of less than 15 kgf/mm², between loading and unloading at a strain of 2% during unloading after loading up to 4%, and (5) a small residual strain Z of less than 0.15%.

5 Such an NiTi-based guidewire of the present invention is superior in the pushability, torque transmission, and re-insertability (reusability) required in use for a medical guidewire. The required characteristics are governed by (1) the straightness of
10 the wire and the characteristics (2) to (5) in a stress-strain curve of wire tensile tests.

Table 1 shows the results of studies of the inventors regarding the relationship between the characteristics of a guidewire of the present invention
15 and the pushability, torque transmission, and re-insertability (reusability) required when used as a medical guidewire.

Table 1

Characteristics of guidewire					Characteristics and effects when used as medical guidewire
(1) Straightness b	(2) Yield point P	(3) Apparent modulus of elasticity Ed	(4) Stress difference H	(5) Residual strain Z	
---	None	Large	---	---	Good pushability - able to be inserted close to end
---	---	---	---	Small	Good in shape recovery - able to be re-inserted (reused)
High	---	---	Small	---	Good torque transmission - improved steerability

As shown in Table 1, in the shape and characteristics of the stress-strain curve in a wire tensile test, when there is no yield point, the larger the apparent modulus of elasticity E_d , the better the pushability and the more the guidewire can be inserted close to the end of the blood vessel. The smaller the strain Z , the more elastic the guidewire becomes and the more it can be reinserted.

Also, the smaller the stress difference H , the better the torque transmission and the better the controllability by the doctor. Furthermore, a high straightness of a wire improves the torque transmission.

Next, in the present invention, by making the apparent modulus of elasticity 350 kgf/mm^2 or more at a strain of 4% and the residual strain when loading up to a strain of 4% and then removing it less than 0.10%, the characteristics of a guidewire for medical use can be further exhibited.

The NiTi-based alloy wire of the present invention is chosen from the group of any of (1) an NiTi alloy containing 50.2 to 51.5 at% of Ni and a remainder of Ti, (2) an NiTi-based alloy containing 49.8 to 51.5at% of Ni, 0.1 to 2.0 at% of one or more of Cr, Fe, V, Al, Cu, Co, and Mo, and a remainder of Ti, and (3) an NiTi-based alloy containing 49.0 to 51.0 at% of Ti, 5.0 to 12.0 at%

of Cu, 0.1 to 2.0 at% of one or two kinds of Cr, Fe, V, Al, Co and Mo, and a remainder of Ni.

One application of a medical guidewire of the present invention is a catheter guidewire. The present
5 invention can be used for all or part of a catheter guidewire.

Note that a guidewire of the present invention can be freely deformed by hand in hot water at 60°C for shaping easy to be inserted into a blood vessel just by
10 immersing the tip in.

[2] The second aspect of the present invention relates to a method of producing a medical guidewire according to the first aspect of the invention.

Namely, the present invention provides a method of
15 producing a medical guidewire comprising by mechanical straightening a cold drawn NiTi-based alloy wire, while applying a tension of 18 kgf/mm² or more, under conditions of a torsional shear strain of 2 to 50%, a temperature of 100 to 275°C, and a range of abcdefg shown
20 in Fig. 7 so as to obtain an NiTi-based alloy guidewire having the characteristics described in the above first aspect of the invention.

Below, a method of producing an NiTi-based medical guidewire of the present invention will be explained in
25 detail.

The present invention is produced by successively hot working an NiTi-based alloy ingot, cold drawing a wire, and then mechanical straightening the wire.

In the above cold drawing, intermediate annealing is
5 suitably carried out, but the cold-wire is finally cold drawn. The reduction rate of the drawn wire to be mechanically straightened is appropriately 10 to 60%.

Note that the method of production of the present invention is fundamentally different from the method of
10 production of a superelastic wire of the related art (hot working - cold drawing - heat treatment for giving superelasticity), the method of production of a cold drawn, hardened wire (hot working - cold drawing), and the method of production of a cold drawn, low temperature
15 heat-treated wire.

Namely, the method of production of the present invention mechanically straightens a cold drawn NiTi-based alloy wire under conditions of a torsional shear strain of 2 to 50%, a temperature of 100 to 275°C, and
20 the range of abcdefg shown in Fig. 7. While applying a tension of 18 kgf/mm² or more so as to obtain a medical guidewire having the characteristics (1) to (5) described in the above first aspect of the invention.

The above mechanical straightening is an important
25 process most affecting the characteristics of the

obtained NiTi-based alloy wire.

The mechanical straightening in the present invention is performed in the predetermined range of torsional shear strain and temperature shown in Fig. 7
5 while applying a tension of 18 kgf/mm².

The reason why the above tension was set to 18 kgf/mm² or more and the conditions of the torsional shear strain and temperature were set as such is because an NiTi-based alloy wire having the above characteristics
10 (1) to (5) cannot be obtained outside the range of these conditions.

For example, when the temperature of the wire under being worked exceeds 275°C, a yield point due to stress-induced martensitic transformation appears, the stress
15 difference becomes large, and characteristics at use such as the pushability and torque transmission decline.

Also, when the temperature is less than 100°C, sufficient straightness cannot be obtained.

Also, the maximum limit of the torsional shear
20 strain (as in Fig. 7) was set to 50% because the wire breaks in the straightening when exceeding the level.

Note that the tension at the mechanical straightening is 18 kgf/mm² or more, but suitably is about 50 to 170 kgf/mm².

25 The twisting in the present invention is performed

using the method comprising, as shown in Figs. 8 and 9,
heating the wire in a heating furnace, fixing one end of
the wire 9 by a fixing member 10, applying tension by a
weight 11 on the other end, and turning either one of the
5 fixed side or weighted side.

Also, as shown in Fig. 10, it is possible to apply
tension on the wire 9 wound on a bobbin 14 and pass it
through the heating furnace 12 and, while doing so rotate
the bobbin to give torsion to the wire so as to enable
10 continuous production. The method of production shown in
Fig. 8 is the most preferable in terms of productivity.

Furthermore, a spinner type straightener or a blade
type straightener etc. which add a slight bending to the
twisting can be also used.

15 In that case, if not heating by the heating furnace
as explained above, heat is generated by friction between
the fast spinning straighteningtop and the wire, so the
wire substantially becomes the temperature of the present
invention and a medical guidewire of the present
20 invention is obtained in some cases.

Note that since the dislocation of strain introduced
by the twisting differs in direction from the dislocation
introduced by cold drawing, the residual strain can be
eased and dislocation density can be increased, so a wire
25 where almost no permanent deformation occurs even if

large strain of 4% is given and satisfying the other required values of (1) to (5) can be obtained.

In the present invention, the mechanical straightening giving torsional strain is the most
5 important process in obtaining the characteristics of the wire of the present invention. A just cold drawn wire does not have any yield points or inflection points, but straightness of the wire cannot be obtained. Further, when a strain of 4% is given, permanent deformation
10 occurs and the residual strain is large. Such a guidewire permanently deforms when passed through a blood vessel having a sharp curve and can no longer be inserted further. Thus, a cold drawn wire cannot be used as a medical guidewire.

15 This is further improved by the mechanical straightening of the present invention. By leaving dislocation due to working strain in a direction other than the wire drawing direction (circumferential direction with respect to wire) by the straightening, it
20 is possible to obtain the superior characteristics of the present invention, that is, a high straightness, large apparent modulus of elasticity, and small residual strain.

BRIEF DESCRIPTION OF DRAWINGS

25 Figure 1 gives explanatory views of a variety of

stress-strain curves in tensile tests of a metal wire,
wherein Fig. 1A shows the case of an NiTi-based wire of
the present invention. Figure 1B shows the case of a cold
drawn NiTi-based wire, Fig. 1C the case of a cold drawn,
5 low temperature heat-treated NiTi-based wire, Fig. 1D a
superelastic wire, and Fig. 1E a highly worked stainless
steel wire.

Figure 2 is a view of a general stress-strain curve
in a tensile test of an NiTi-based alloy showing a yield
10 point F, an apparent modulus of elasticity $E_d = \sigma_1 / \epsilon_1$, a
stress difference H, and a residual strain Z.

Figure 3 is an explanatory view of the method of
finding the straightness by the method of suspending a
medical guidewire.

15 Figure 4 is an explanatory view of the method of
measuring the torque transmission.

Figure 5 is a view of the relationship of a drive
angle and a follow angle showing the torque transmission.

Figure 6 is a view of the change in heat in
20 differential scan calorimetry (DSC) for investigating
phase transformation and structural changes of an alloy
wire, wherein (A) shows the case of an NiTi-based wire.
Also, (C) shows the case of a cold drawn, low temperature
heat-treated type NiTi wire and (D) a superelastic NiTi-
25 based wire.

Figure 7 is an explanatory view of the range abodef of conditions of the torsional shear strain and temperature in mechanical straightening in the present invention.

5 Figure 8 is an example of mechanical straightening in the present invention.

Figure 9 is another example of mechanical straightening in the present invention.

10 Figure 10 is another example of continuous mechanical straightening of the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

Below, embodiments of the present invention will be explained in detail by a comparison with comparative examples and conventional examples.

15 Below, a first embodiment of the present invention will be explained.

First Embodiment

20 Cast ingots of an NiTi-based alloy containing 51.0 at% of Ni and the remainder of Ti (Sample Nos. 1 to 10 shown in Table 2) were hot worked and cold drawn to produce wires having a diameter of 0.35 mm with a final cold working rate of 55% after annealing in the above cold drawing.

25 These were mechanically straightened by rotation of the bobbin shown in Fig. 10 to produce medical

guidewires.

In the above mechanical straightening, the tension was set to 75 kgf/mm² and the torsional shear strain and temperature were set so that the relationship of the two
5 came within the range of abcdefg in Fig. 7.

Also, medical guidewires were produced by the same method as described above except for using a Cr alloy cast ingot of 48.9 at% of Ni and 0.2 at% of Ti (Sample No. 11 shown in Table 2) and an Fe alloy cast ingot of
10 50.0 at% of Ni, 8.0 at% of Ti, and 0.2 at% of Cu (Sample No. 12 shown in Table 2), a

(Comparative Examples)

Next, as comparative examples, cast ingots of NiTi alloy containing 51.0 at% of Ni and the remainder of Ti
15 (Sample Nos. 13 to 22) were hot worked and cold drawn to produce wires having a diameter of 0.35 mm with a final cold working rate of 55% after annealing in the above cold drawing.

These were mechanically straightened by rotation of
20 the bobbin shown in Fig. 10 to produce medical guidewires.

In the above mechanical straightening, the tension was set to 75 kgf/mm² and the torsional shear strain and temperature were set to give a relationship of the two
25 out of the range of abcdefg (below bodef) in Fig. 7 to

produce comparative medical guidewires.

The production conditions of the examples of the invention and comparative examples are shown in Table 2.

(Conventional Examples)

5 NiTi alloy (Sample Nos. 23 to 25) cast ingots containing 51.0 at% of Ni and the remainder of Ti were processed in the same way as Sample No. 1 up to the cold working.

 Sample No. 23 is a test material only cold drawn
10 (cold drawn wire).

 Sample No. 24 is a cold drawn, low temperature heat-treated wire obtained by heat treating a cold drawn material at a low temperature (350°C for 10 seconds).

 Sample No. 25 is a superelastic wire obtained by
15 heat treating a cold drawn material (420°C for 60 seconds).

 Sample No. 26 is a stainless steel wire having a drawing rate of 57%.

 The thus produced test wires were measured for the
20 (1) straightness of the wires. The straightness was measured by the suspension method shown in Fig. 3 as explained above.

 Also, a tensile test was conducted for each of the test wires to find the stress-strain curve. The (2) shape
25 of the stress-strain curve up to the strain of 4%, (4)

the stress difference H (stress hysteresis) at a strain of 2% after deformation up to the strain of 4% and then removal of the stress, (5) the residual strain Z after deformation up to 4% were then found.

5 The test results are shown all together in Table 2.

Table 2

TABLE 2

Sample no.	Mechanical straightening			Characteristics of guidewire					Characteristics in use		
				Characteristics of stress-strain curve							
	Temp. (°C)	Tension (kgf/mm ²)	Torsional shear strain (%)	(1) Strai-ghtness b (mm)	(3) Apparent modulus of elasticity E _d (kgf/mm ²)	(4) Stress difference H (kgf/mm ²)	(5) Residual strain (%)	Push-ability	Torque trans-mission	Reuseab-ility	
Inv. Ex.											
1	100	75	17.0	19.0	3470	12.8	0.10	Good	Good	Good	
2	100	75	23.0	15.0	3530	12.6	0.10	Good	Good	Good	
3	100	75	25.0	13.0	3490	12.7	0.09	Good	Good	Good	
4	150	75	10.0	7.5	3390	12.8	0.06	Good	Good	V. Good	
5	150	75	15.0	3.8	3330	12.7	0.07	Good	Good	V. Good	
6	200	75	2.5	20.0	3380	12.4	0.05	Good	Good	Good	
7	200	75	5.0	12.0	3290	12.6	0.04	Good	Good	Good	
8	200	75	10.0	3.0	3340	12.9	0.04	Good	Good	V. Good	
9	260	75	2.5	8.0	3130	11.1	0.01	Good	Good	V. Good	
10	260	75	5.0	2.0	3100	11.0	0.02	Good	Good	V. Good	
11	260	75	10.0	10.0	3300	11.0	0.07	Good	Good	V. Good	
12	250	75	5.0	3.0	3500	10.5	0.04	Good	Good	V. Good	

Comp. Ex.	50	75	10.0	150.0	3550	18.7	0.19	Good	Poor	Pair
13	50	75	10.0	150.0	3550	18.7	0.19	Good	Poor	Pair
14	50	75	20.0	65.0	3690	16.5	0.16	Good	Poor	Pair
15	50	75	30.0	51.0	3660	17.2	0.17	Good	Poor	Pair
16	100	75	0.0	135.0	3700	12.3	0.10	Good	Poor	Good
17	100	75	5.0	75.0	3500	12.1	0.09	Good	Poor	Good
18	100	75	10.0	37.5	3630	12.6	0.10	Good	Pair	Good
19	150	75	0.0	75.0	3340	11.9	0.08	Good	Poor	Good
20	150	75	5.0	22.5	3380	12.4	0.07	Good	Pair	Good
21	200	75	0.0	37.5	3220	11.8	0.04	Good	Pair	Good
22	260	75	0.0	25.0	3090	10.8	0.02	Good	Pair	Good
Conv. Ex.	Cold drawn			105.0	4472	37.4	0.40	Good	Poor	Poor
23	Cold drawn			70.0	2875	45.5	0.02	Pair	Poor	Good
24	Cold drawn low temp. heat-treated			30.0	1568	29.7	0.07	Poor	Pair	Good
25	Superelastic									
26	High worked stainless steel wire			30.0	Broke at 1.8% strain			Poor	Pair	Poor

Note: Nos. 1 to 10 and Nos. 13 to 25 are Ni-Ti alloys, No. 11 is Ni-Ti-Cr alloy, and No. 12 is Ni-Ti-Cu-Pa alloy.

The (2) shapes of the stress-strain curves up to a strain of 4% of the examples of the present invention (Sample Nos. 1 to 12) and comparative examples (Sample Nos. 13 to 22) were by and large the same as in Fig. 1A.

5 Also, the (2) shapes of the stress-strain curves up to a strain of 4% of Sample Nos. 23 to 26 of the conventional examples were as shown in Fig. 1B, 1C, 1D, and 1E, respectively.

As clear from the test results of Table 2, it was
10 confirmed that the guidewires of the present invention were superior in all of the characteristics of (1) straightness, (3) apparent modulus of elasticity, (4) stress difference, and (5) residual strain as characteristics of the stress-strain curve and exhibited
15 pushability, torque transmission, and reusability as characteristics of use as a medical guidewire.

As opposed to this, the guidewires of the comparative examples (Sample Nos. 13 to 22) were poor in some of the characteristics of use since one or more the
20 characteristics as a guidewire were out of the range of the present invention.

Also, as clear from the Table 2, the guidewires of the conventional examples (Sample Nos. 23 to 26) were inferior in one or more of the characteristics as a
25 guidewire, so were poor in one or more of the

characteristics of use as a medical guidewire.

Second Embodiment

Cast ingots of an NiTi alloy containing 51.0 at% of Ni and the remainder of Ti (Sample Nos. 31 to 39 shown in Table 3) were hot worked and cold drawn to produce wires having a diameter of 0.35 mm with a final cold working rate of 55% after annealing in the above cold drawing.

These were mechanically straightened by rotation of the bobbin shown in Fig. 10 to produce medical guidewires.

In the above mechanical straightening, the tension was changed between 18 to 170 kgf/mm², the torsional shear strain was made 20% or 30%, and the temperature was made 100°C or 200°C.

(Comparative Examples)

The same procedure was followed as in the second embodiment to produce medical guidewires (Sample Nos. 40 to 42 in Table 3) except for making the tension in the mechanical straightening less than 18 kgf/mm², which is out of the range of the present invention.

The test wires were tested and evaluated in the same way as the first embodiment. The results are shown in Table 3.

Table 3

Sample no.	Mechanical straightening			Characteristics of guidewire				Characteristics in use		
	Temp. (°C)	Tension (kgf/mm ²)	Torsional shear strain (%)	(1) Straightness b (mm)	Characteristics of stress-strain curve			Push-ability	Torque transmission	Reusability
					(2) Apparent modulus of elasticity E _d (kgf/mm ²)	(4) Stress difference H (kgf/mm ²)	(5) Residual strain (%)			
Inv. Ex.										
31	100	50	30.0	15.0	3590	12.7	0.08	Good	Good	Good
32	100	100	30.0	15.0	3570	12.8	0.10	Good	Good	Good
33	100	147	30.0	14.0	3600	12.6	0.09	Good	Good	Good
34	100	170	30.0	13.0	3630	12.6	0.10	Good	Good	Good
35	200	18	20.0	15.0	3290	12.3	0.05	Good	Good	Good
36	200	50	20.0	7.0	3280	12.4	0.06	Good	V. Good	Good
37	200	100	20.0	5.0	3320	12.5	0.05	Good	V. Good	Good
38	200	147	20.0	3.0	3330	12.2	0.05	Good	V. Good	Good
39	200	170	20.0	3.0	3370	12.0	0.06	Good	V. Good	Good

Note that the (2) shapes of the stress-strain curves up to a strain of 4% of the examples of the present invention and comparative examples were substantially the same as in Fig. 2A.

5 As clear from the test results of Table 3, it was confirmed that the guidewires of the present invention (Sample Nos. 31 to 39) are superior in all of the characteristics of (1) straightness, (3) apparent modulus of elasticity, (4) stress difference, and (5) residual
10 strain as characteristics of the stress-strain curve and exhibit pushability, torque transmission, and reusability as characteristics in use as a medical guidewire.

 As opposed to this, the guidewires of the comparative examples (Sample Nos. 40 to 42) were found to
15 be inferior in one or more of the characteristics in use since one or more of the characteristics as a guidewire were out of the range of the present invention.

 As explained above, a method of producing an NiTi-based guidewire of the present invention and an NiTi-based guidewire obtained by the method of production of
20 the same give excellent pushability, torque transmission, and reusability as catheter or other guidewires and therefore suitability as a medical guidewire.

INDUSTRIAL APPLICABILITY

25 A medical guidewire of the present invention is used

- 34 -

for a catheter guidewire, endoscope guidewire, etc.

CLAIMS

1. An Ni-Ti-based medical guidewire comprised of an NiTi-based alloy wire made of a wire produced by mechanical straightening a cold drawn NiTi-based alloy wire and (1) having a straightness of 20 mm/1.5 m as
5 determined by the suspension method and having a shape and characteristics of the stress-strain curve in a wire tensile test which satisfy the following requirements (2) to (5) and thereby displaying excellent pushability,
10 torque transmission, and reusability as a medical guidewire.

Requirement (2) to (5):

(2) A monotonous increase in loading up to strain of 4% without any yield points or inflection points and
15 no stress-induced martensitic transformation shown at all.

(3) High elasticity characteristics over a wide range of strain and an apparent modulus of elasticity of 3000 kgf/mm² or more at a strain of 4%.

20 (4) A residual strain after loading up to strain of 4%, then unloading of not more than 0.15%.

(5) A stress difference, between loading and unloading, at a strain of 2% after loading up to 4% strain, then unloading, of not more than 15 kgf/mm².

25 2. An NiTi-based medical guidewire as set forth in

claim 1, wherein the apparent modulus of elasticity at a strain of 4% in the characteristic (3) in claim 1 is 3500 kgf/mm² or more and the residual strain after loading a strain of 4% and unloading is not more than 0.10%.

5 3. An NiTi-based medical guidewire as set forth in claim 1 or 2, wherein the NiTi-based alloy wire is comprised of any of (1) an NiTi alloy containing 50.2 to 51.5 at% of Ni and a remainder of Ti, (2) an NiTi-based alloy containing 49.8 to 51.5 at% of Ni and 0.1 to 2.0 at% of at least one element selected from Cr, Fe, V, Al, Cu, Co, and Mo, and a remainder of Ti, and (3) an NiTi-based alloy containing 49.0 to 51.0 at% of Ni, 5 to 12 at% of Cu, 0.1 to 2.0 at% of at least one of Cr, Fe, V, Al, Cu, Co, and Mo, and the remainder of Ti.

10 4. An NiTi-based medical guidewire as set forth in any one of claims 1, 2, and 3, wherein the medical guidewire is a catheter guidewire or is used for at least a part of a catheter guidewire.

15 5. An NiTi-based medical guidewire as set forth in any one of claims 1, 2, and 3, wherein the medical guidewire is an endoscope guidewire or is used for at least a part of an endoscope guidewire.

20 6. A method of production of an NiTi-based medical guidewire according to claim 1, comprising obtaining an
25 NiTi-based guidewire having the characteristics as set

forth in claim 1 by applying a tension of 18 kgf/mm² or more to a cold drawn NiTi-based alloy wire and mechanically straightened it under conditions of a torsional shear strain of 2 to 50%, a temperature of 100 to 275°C, and a range of abcdef shown in Fig. 7.

7. A method of production of an NiTi-based medical guidewire as set forth in claim 6, wherein a cold working rate of the NiTi-based alloy wire supplied for the mechanical straightening is 10 to 60%.

10 8. A method of production of an NiTi-based medical guidewire as set forth in claim 6 or 7, wherein said tension is 50 to 170 kgf/mm².

9. A method of production of an NiTi-based medical guidewire as set forth in any one of claims 6, 7, and 8, wherein said mechanical straightening of the NiTi-based alloy wire is performed by applying tension on a wire wound on a bobbin and rotating the bobbin to give torsional strain to the wire while passing it through a heating furnace as shown in Fig. 10 for continuous mechanical straightening.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP99/06184

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl.⁷ A61M25/09, B21F7/00, C22F1/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl.⁷ A61M25/09, B21F7/00, C22F1/10

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1926-1996 Toroku Jitsuyo Shinan Koho 1994-2000

Kokai Jitsuyo Shinan Koho 1971-2000 Jitsuyo Shinan Toroku Koho 1996-2000

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, 5069226, A1 (Tokin Corporation, Terumo K.K.), 03 December, 1991 (03.12.91), Full text & JP, 2-289265, A & EP, 395098, B1	1-9
A	JP, 2-11723, A (Hiroyuki Kanei), 16 January, 1990 (16.01.90), page 1; left column; Claims (Family: none)	1, 6, 9

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

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Date of the actual completion of the international search
18 January, 2000 (18.01.00)Date of mailing of the international search report
08 February, 2000 (08.02.00)Name and mailing address of the ISA/
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